RESEARCH DEPARTMENT

Calculation of the field strength required for a television service, in the presence of co-channel interfering signals

Part 1: The assessment of a single interfering source

RESEARCH REPORT No. RA-12/1

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

CALCULATION OF THE FIELD STRENGTH REQUIRED FOR A TELEVISION SERVICE, IN THE PRESENCE OF CO-CHANNEL INTERFERING SIGNALS

Part 1: The Assessment of a Single Interfering Source

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PREFACE

The report on 'Calculation of the Field Strength Required for a Television Service, in the Presence of Co-channel Interfering Signals' is in three parts, as follows:

Part 1: The assessment of a single interfering source

Part 2: Effect of multiple interfering sources

Part 3: The computer programme

Parts 1 and 2 deal with the theoretical background of the subject, and have been written as entities which can be read separately; for a full understanding of the work, however, the reader is advised to study Parts 1 and 2 together. Part 3 describes the form and flow diagram of the computer programme to carry out the calculation processes described in Parts 1 and 2.

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Part 1: The Assessment of a Single Interfering Source

SUMMARY

One factor which affects the limit of the service area of a television station is the interference from other stations which are operating in the same frequency channel. In order to use the limited number of available channels effectively it is essential that the degree of this interference be predicted as accurately as possible. This will permit the formulation of a plan which will ensure that the service reaches the maximum number of viewers, substantially free from the effects of such interference. It is desirable that the assessments should be based upon an internationally-accepted method of calculation, because this simplifies liaison between countries when they are negotiating clearance for new stations.

Experience has shown that the existing methods are not sufficiently accurate, nor do they cover all the requirements for the planning of u.h.f. television networks. An improved prediction method is therefore proposed. Moreover, because of the large number of stations planned for operation in the u.h.f. band, and hence the large number of calculations involved, the method has been developed for calculation using a digital computer.

The report is divided into three parts, published separately. Part 1 covers the method proposed for calculating the field strength of each interfering source. Part 2(1) *deals with the effect of multiple interfering sources on the field strength required for a satisfactory television service. Part 3*(2) *gives the computer programme for carrying out the calculations.*

1. INTRODUCTION

The limit of the service area of a television transmitter is defined by the range beyond which impairment of the picture or sound quality by some form of interference causes the service to become unacceptable. This limit may be established by receiver noise, or it may be due to various forms of interference, including that from stations working on the same channel (co-channel interference). These comments apply equally, of course, to television transmissions in both the v.h.f. and u.h.f. bands. However, the work described in this report is that associated with the u.h.f. service (although similar techniques are applicable to the v.h.f. service) because the particularly exacting problems experienced during the preliminary planning of the u.h.f. network demanded the development of the new techniques.

In preparing a plan for a network of television stations it is first necessary to decide what standard of service shall be used as a basis for the calculations. In the absence of co-channel interference (c.c.i.), the standard is likely to be established by the noise levels of the receivers and their ability to reproduce the wanted signal. If several stations occupy the same channel, the standard of service may be determined by the influence of c.c.i. Because the strength of a signal from a distant interfering station will vary with time, interference may be perceptible only for certain periods. Furthermore, some receiving locations may suffer c.c.i., whilst others may not. Thus the statement which defines the standard of service must be in terms of the percentage of receiving locations which are likely to be free from c.c.i. for a stated percentage of the time.

The plan for the high-power u.h.f. television stations in the United Kingdom was presented to the European Broadcasting Conference at Stockholm in 1961. The limits of the service areas for stations in this network were defined by the ranges at which a field strength of at least 70 dB (μV/m) at 10 m a.g.l. was achieved at not less than 50% of the receiving locations. The standard of protection chosen was freedom from c.c.i. for at least 50% of the locations for not less than 99% of the time. It is important to note that the factor common to both of these statements is the 50% of receiving locations. The propagation curves which were used to plan the services were generally based upon such values, i.e., they displayed the 50% receiving-location field strengths as a function of distance from the transmitting station. With the help of such curves it is, therefore, a simple process to predict the values of both the wanted and unwanted signals. However, there are many complications which are revealed when more precise answers are required, and these difficulties will be discussed in this report. At this stage it is sufficient to note that the technical data which were used at the Stockholm Conference were assembled into one publication (hereafter referred to as the Stockholm document$^{(3)}$), and this record of internationally-approved information has remained the basis for transmitting station (frequency) planning for some time.

The methods of predicting field strengths described in the Stockholm document are essentially statistical. Any attempt to improve the accuracy increases the labour of calculation, because it must take into account details appropriate to the particular propagation path which is being studied. Even the use of the relatively simple methods described in the Stockholm document still leaves a formidable calculation problem, if adequate results are to be obtained to plan the service. Some idea of the magnitude of the work can be gained if it is realized that about 200,000 individual calculations of c.c.i. levels are required to produce one complete assessment of the existing plans for the United Kingdom u.h.f. network. Moreover, the calculations are based upon the details relating to the siting of the transmitters, their powers, aerial heights and frequencies, so that changes in any of these parameters may invalidate existing results. Because the predictions affect, and in many cases dictate, the specifications relating to the transmitter installation and its siting, it is most important that comprehensive data are constantly available. Thus a process of continuous calculation is involved in keeping the records up-to-date despite changes in the plan.

As a result of early attempts to employ the Stockholm document methods in the planning of the dense network of u.h.f. relay stations, it was soon concluded that while these techniques were adequate for devising a frequency plan for a system of comparatively widely-spaced high-power stations, they were unsuited to the new requirements. Furthermore, it was clear that the enormous number of computations could not be completed manually. The calculations are simple, but they are tedious and time-consuming, and this unfortunate combination can give rise to many errors if manual methods are used. A digital computer is ideally suited to the work, although an extremely complicated programme is necessary and the data storage demands are prodigious. However, it was considered that the advantages offered by a technique based upon computer calculation greatly outweighed the disadvantages, and accordingly such a system has been devised.

The primary objectives of this report are to summarize the difficulties which have been met in applying the Stockholm document methods, and to describe an improved system which is especially developed for calculation by a digital computer.

2. LIMITATIONS OF THE STOCKHOLM DOCUMENT METHOD

2.1. General

In order to produce the necessary data in a form which allowed rapid application, the Stockholm document contained many simplifying assumptions. In the words of the document '... engineering judgment must always be used in interpreting the results.' The implication of this statement is that the errors which are inherent in the system can to some extent be corrected by the user, provided he is sufficiently familiar with the peculiarities of each problem. However, a large-scale development such as the u.h.f. network cannot be based upon spontaneous and unique subjective assessments. An objective method is clearly desirable, at least in order to ensure consistency. Nevertheless, the Stockholm document was adequate for the planning of the main stations that was carried out in 1961, indeed it would have been impossible to proceed without it. Furthermore, it still remains essential for present-day negotiations because it contains data which are internationally agreed.

The majority of the difficulties which have been met were associated with the means of determining the field strength values of the unwanted signals. The propagation curves which are included in the Stockholm document are not wildly inaccurate; within their limitations, they are a useful guide. It is only when an attempt is made to employ them to assess the field strength at a precise location that difficulties occur. Indeed, the principal difference between the planning work that is required for main stations and that which is necessary for the lower-power relay stations is in the degree of detail. Where the service area is large, as in the case of main stations, the investigation of the c.c.i. levels at a dozen points around the periphery is generally adequate to allow the necessary recommendations to be made for the transmitting installation. For the relay stations, the same number of assessments may be required, but here the density of these points is much higher because of the smaller dimensions of the service area. There are two reasons for this closer examination. Firstly, because the range of the station is small, slight movements around the service area can produce pronounced changes due to the influence of receiving aerial directivity. Secondly, the effect of local terrain can be very important, because it can screen a significant proportion of receiving aerials from some of the interfering transmissions. Both of these features can be used to advantage if accurate information is available about the c.c.i. levels over the potential service area of the relay station. The results can then be used to specify the site and other technical requirements of the station to minimize c.c.i.

In addition to increasing the density of the points examined, it is also important to be explicit about the way in which the predicted field strength will vary with movement away from the representative receiving site which has been chosen for calculation. The Stockholm propagation curves give the median or '50% location' field strength, but a higher percentage-location coverage is more appropriate to areas of dense population. Furthermore, part of the calculation is concerned with the comparison between the statistical time-distributions of the protected field strength (that which is required to achieve virtually interference-free reception) and the wanted field strength (that which is available from the wanted station). In order to obtain a realistic assessment it is essential to define the ways in which each of these distributions vary with receiving location.

In the following sections the limitations of the Stockholm data are discussed in more detail, and the results of investigations into means of improvement are described.

2.2. The Propagation Curves

Propagation curves, giving field strength as a function of distance from the transmitting aerial, are usually plotted on a median receiving-location basis, i.e. they give field strengths exceeded at 50% of locations at the specified distance. The measurements which were used to compound the propagation curves shown in the Stockholm document were made by several authorities, and separate results are given for land paths and sea paths. The majority of the data used for the sea paths came from long-distance propagation experiments over the North Sea. Many different results have been used for the land paths, and the curves in the Stockholm document are stated to be representative of the propagation over the 'rolling, irregular terrain of Europe.'

The propagation curves are displayed as a family, with percentage of time as parameter; thus, results are shown for field strengths exceeded for 1%, 10% and 50% of the time. Because the fading range becomes greater as the distance from the transmitting aerial increases, the divergence between field strengths for the time percentages quoted becomes greater. The field strength is a function of location as well as of time. The Stockholm document assumes that the deviation of field strength (measured in decibels) from the median value for different location percentages follows a Normal statistical distribution. Curves are given which show the extent of the variation, and these curves are reproduced in Fig. 1. The variation increases with the depth of ground irregularity, and the Δh parameter* is used to define this. It will be seen that the abscissae of this graph are 'percentage receiving locations', so that if the user is interested in a particular receiving site, he must decide the amount by which the field strength will be different from the median value given by the propagation curve. There are two important objections to this process. Firstly, there is the intrusion of a subjective assessment. Secondly, a limit is not placed upon the dimensions of the area for which a Normal distribution results; some investigation has been carried out on this point, because it is of great importance to the prediction.

Measurements of field strength made in several towns in the United Kingdom have been analysed to determine the distribution of values obtained over different areas within the towns. There is strong evidence from this work to show that the effects of local hills and other forms of screening make it difficult to fit the results to a simple distribution law. This is illustrated by Fig. 2, in which the field strength measurements obtained in the city of Guildford have been plotted as a series of histograms. Firstly, the overall distribution is shown, and it will be seen that this is certainly not Normal.

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* $\Delta h = (H_{10} - H_{90})$ metres
where H_{10} is the height in metres exceeded for 10% of the path between 10 and 50 km from the transmitter, and H_{90} is the height in metres exceeded for 90% of the same range.

However, if the town is divided into small areas, the limits of which are decided after considering the features of the local terrain, more or less Normal distributions result for each part. The controlling feature is the degree of terrain roughness, and in this case the separate areas have been delineated so that each one is substantially free from significant variations in the ground level, and from important differences in the overall propagation path to the area. Although it is by no means a firm rule, examination of many such results shows that a Normal distribution is unlikely to occur if the range between maximum and minimum measurement exceeds 30 dB. If reference is again made to Fig. 1 it will be seen that the range between 1% and 99% of locations for $\Delta h = 50$ m is about 44 dB, a degree of variation well outside the limit which measurements suggest should be applied for Normal distribution. It will be seen later that it is convenient to work in terms of Normal distributions for the calculation method used in this report. We, therefore, define the area over which a particular calculation applies as one in which the ratio of maximum to minimum field strength does not exceed 30 dB. If we take the maximum to minimum ratio as corresponding to six times the standard deviation, this means we regard an 'area' as that for which the standard deviation is 5 dB.

The effect of increasing the height of the transmitting aerial is covered in the Stockholm document by showing a series of propagation curves, each for a particular elevation above 'mean terrain'. The latter is defined as the mean level of the terrain between three and fifteen kilometres from the transmitting station. This form of assessment is reasonable for propagation paths of considerable length, but it becomes increasingly inapplicable as the range diminishes. In particular it is unsuited to those cases where the transmitting aerial is below the mean terrain height, which may often occur at relay stations in mountainous areas. In fact a far more influential feature is the dominance of the terrain in the immediate vicinity of the receiving site, and this point will be discussed later in the report.

Comparison between measurements made at

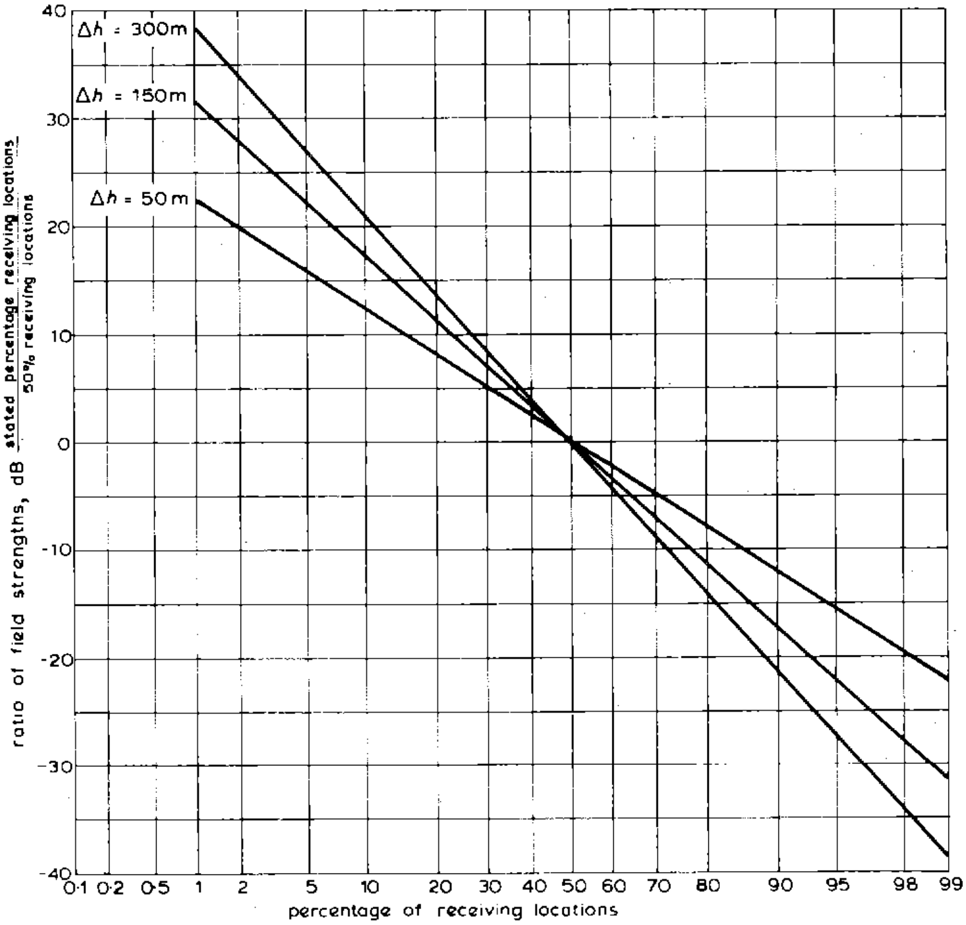

Fig. 1 - Ratio of field strengths for a stated percentage of receiving locations to the 50% value (Stockholm Document Fig. 9)

Δh is the difference in heights exceeded for 10% and 90% of the propagation path in the range 10 to 50 km from the transmitter ranges of up to 110 km and predictions based on the Stockholm document gave disappointing results. Where the service area embraced terrain which was rather hilly, inclusion of the effect of the Δh parameter brought some improvement, but generally this was quite small.

The original method of dealing with propagation over mixed paths, i.e., land and sea, as advocated by the Stockholm document was also unsatisfactory, due mainly to the difficulties which were experienced in its application. However, the C.C.I.R. has now adopted new mixed-path curves(4), and these have solved the problems associated with the Stockholm data in this respect.

2.3. Protection Ratios

When the field strength (in decibels) of the interfering signal has been determined, the wanted service must provide a higher field strength in order that interference effects will be insignificant. This increment is referred to as the protection ratio, defined as the ratio, in decibels, of wanted-to-unwanted signals for a condition of c.c.i. which is judged to be acceptable. The value produced by adding the protection ratio to the unwanted field strength is described as the 'protected field strength.'

The protection ratio depends on the carrier-frequency differences (or 'offsets') between nominally co-channel signals. The Stockholm document contains information concerning the appropriate protection ratios which should be used. There is little to criticise in the amount of data, but in planning stations which will have a small geographical separation, where the c.c.i. may be present for a substantial proportion of the viewing time, it has been necessary to consider what increase must be made to the protection ratios in order to allow for this virtually continuous disturbance. This is because the protection ratios quoted in the Stockholm

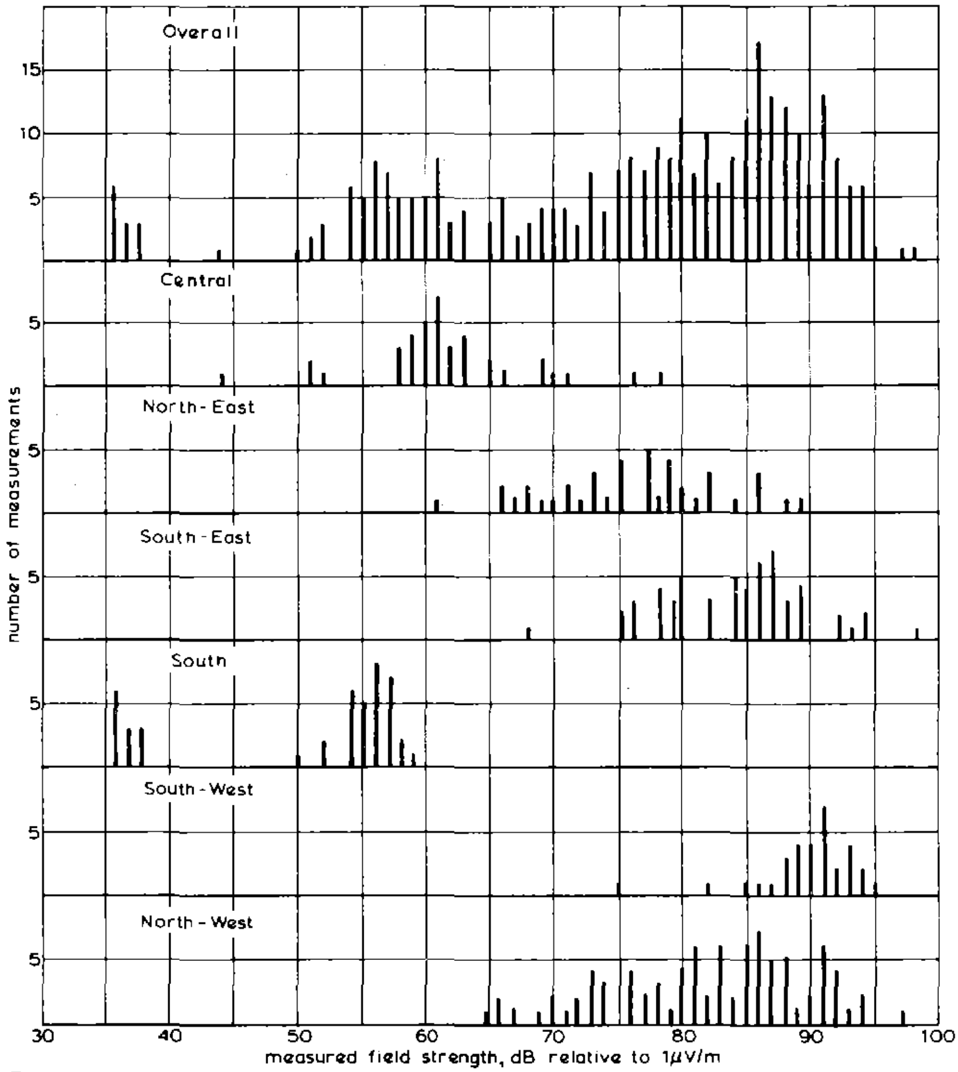

Fig. 2 - Distributions of 300 field strength measurements made in Guildford of the Crystal Palace Channel 33 transmissions

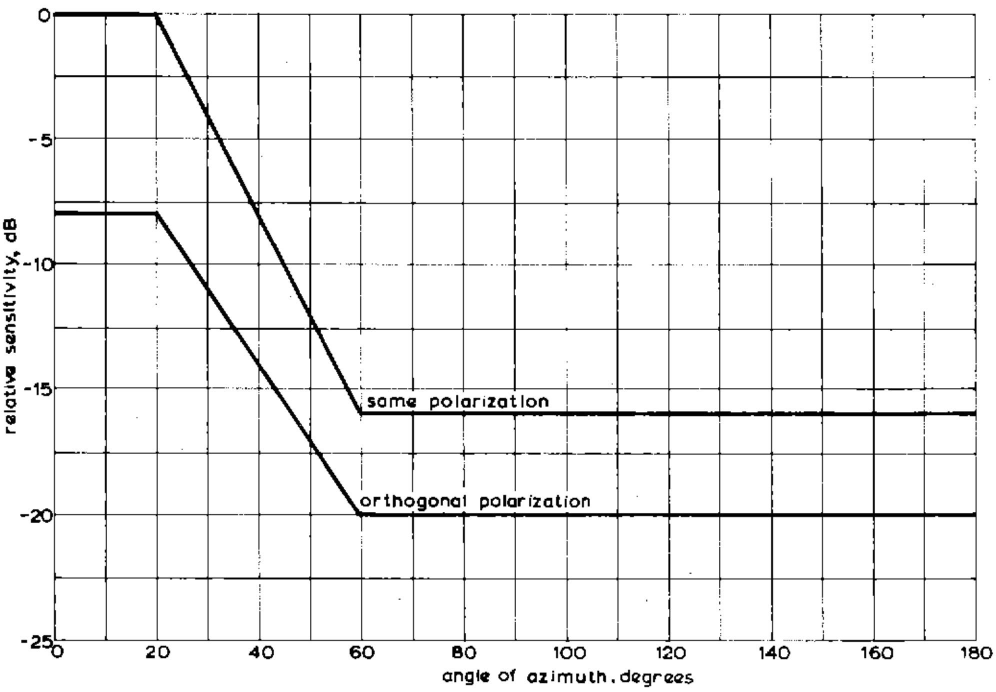

Fig. 3

UHF receiving aerial discrimination curves

Angle relative to direction of main response

document are considered to be acceptable for those cases where interference occurs for a small percentage of the time, '... not precisely defined, but assumed to be between 1% and 10%.' The document goes on to suggest that 'just perceptible interference' would require an increase in the protection ratios of some 10 to 20 dB. Work carried out by the BBC(5) showed that an increase of 10 dB (over the C.C.I.R. 1% to 10% time values) is a sufficient allowance for virtually continuous interference, and this is taken into account in the BBC method.

2.4. Receiving Aerial Directivity

The protection ratios refer in all cases to the ratios, in decibels, between the wanted and unwanted signals at the input to the receiver. Of course, the voltage of the unwanted signal may be reduced by the use of a suitable directional receiving aerial, provided this can discriminate between the directions of the wanted and the unwanted sources. Representative directional aerial radiation patterns are contained in the Stockholm document, and that regarded as applicable to u.h.f. transmissions of the same polarization is reproduced in Fig. 3. Commercial aerials having this performance are available, and in BBC planning it is assumed that such aerials are used. However, in the United Kingdom, horizontal polarization is being used for the main high-power stations and vertical polarization for the relay stations. It has therefore been necessary to extend the data to include the response of a receiving aerial to unwanted, orthogonally-polarized transmissions. The results of experiments carried out by the BBC(6) have resulted in the lower curve shown in Fig. 3.

3. MODIFICATIONS TO THE STOCKHOLM DOCUMENT METHODS

3.1. Development of the Field-Strength Calculation Method

The primary requirement of the prediction process is that it must give, with acceptable accuracy, the values of interfering field strengths which are then used as the basis for the calculation of the protected field strength. We require to know the median value of protected field strength, its standard deviation with respect to time and location, and some idea of the geographical limits over which these values apply.

It was considered that an appreciable increase in the accuracy of prediction using the Stockholm document propagation curves would result if account were taken of the terrain in the immediate vicinity of the receiving site, if only in an empirical manner.

A study was made of measurements taken in the service area of the BBC Crystal Palace Station in relation to the ground profiles for the first five kilometres from each receiving point towards the transmitter. The difference between the measured field strength and the value given by the Stockholm propagation curves was plotted as a function of the angle, θ_5, at the receiving aerial, between the horizontal and the line to the summit of the principal obstacle within five kilometres as illustrated in Fig. 4(*a*). The correction curve shown in Fig. 4(*b*) is a smoothed curve between the points obtained.

The median values derived from several thousand measurements made in 123 built-up areas were compared with the corresponding predicted values obtained using the Stockholm propagation curves. The ratios between the measured and predicted results were expressed in decibels, and the difference indicated the magnitude of the prediction errors. The process was then repeated, but this time a correction was made to the predictions in accordance with the empirical correction curve in Fig. 4(*b*). The results of this comparison are shown in Table 1.

TABLE 1

	Number of built-up areas (total 123) where ratio between predicted and measured values was	
	>20 dB	>10 dB
Prediction without correction	16	56
Prediction with correction	2	15

It was considered that these results were sufficiently promising to justify further development, and the investigation was extended to include results obtained from measurements in other service areas, so that a correction could be obtained which would be representative of all types of terrain encountered in the United Kingdom.

In addition to making a correction for the terrain in the vicinity of the receiving site, it was felt that an improvement could also be realized by using the same technique at the transmitting end. This would overcome some of the objections to the 'height above mean terrain' process mentioned in Section 2.2 and would be quite suitable for short-path calculations. After some study, it was decided that the correctjon factor at each end of the path should be derived for a standardized path length of 15 km (instead of 5 km) from the terminal points.

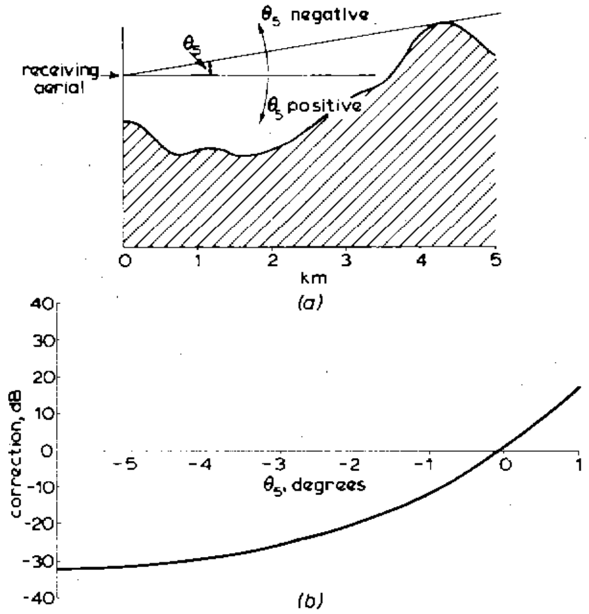

Fig. 4 - Terrain correction
(*a*) Typical profile (*b*) Initial empirical correction

The angle θ_{15} derived for this distance (i.e. the angle subtended at the aerial by the horizontal and a line to the summit of the principle obstacle within 15 km) is called 'the terrain clearance angle' and it will henceforth be denoted θ, the subscript being dropped. This angle can be obtained quite quickly by using the terrain clearance protractor, illustrated in Fig. 5 and described in the Appendix.

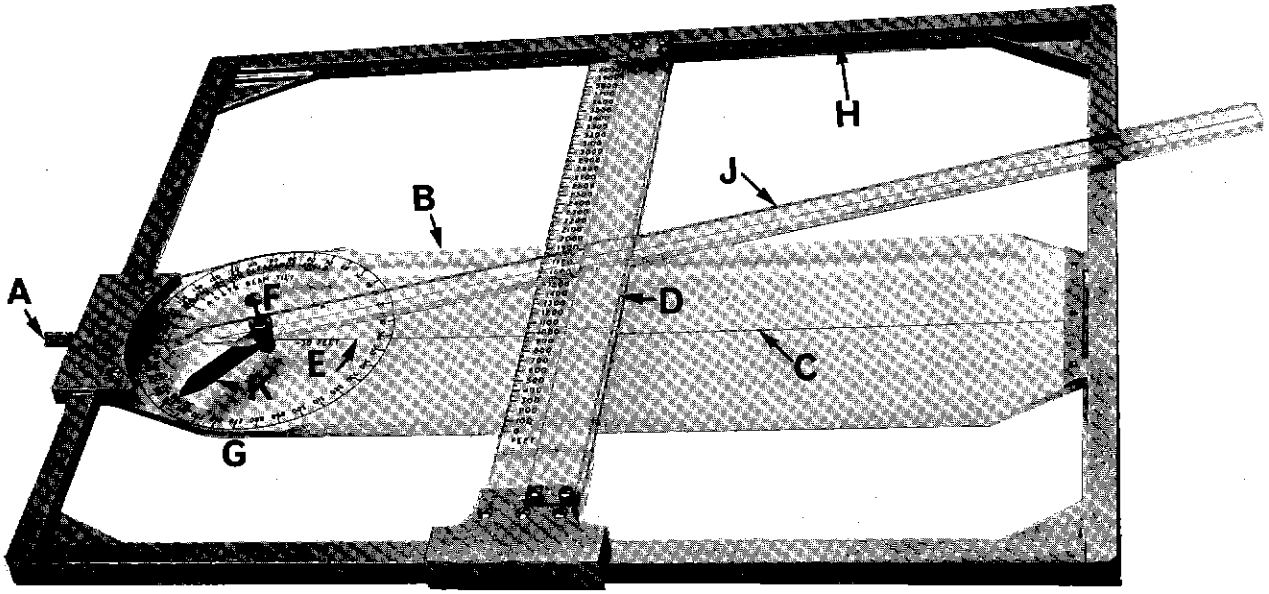

Fig. 5 - Terrain clearance protractor

When this instrument is used, the time taken to produce the terrain clearance angle from an Ordnance Survey map for one radial is less than one minute.

With the establishment of a terrain clearance correction, the new method was employed to produce predictions which could be compared with measured results made over an extensive range of distances from various transmitting stations. Many of the measurements had already been used to produce the Stockholm curves, and it was hoped that the additional terrain clearance correction would give improved accuracy in calculating field strengths. However, the results of this work were disappointing, and upon examination certain inconsistencies were revealed. It was realized that at short ranges the measurements which had been used to produce the Stockholm curves were generally median values obtained from town surveys; on the other hand, at the longer ranges, the receiving sites chosen for measurement were situated in open country, often on hill tops, in order to obtain a sufficiently high field strength to measure. Site variation factors (i.e. the difference between field strength at the fixed receiving site and the mean of the values at a number of other locations scattered over the area) were determined at the time of the original long-range measurements. These factors were used to compensate for the prominent positions of the fixed receiving sites, but did not allow for additional loss due to local buildings (referred to as 'urban loss') which was inherent in the short-range measurements in towns. In addition, towns are frequently in valleys and thus subject to local terrain shadowing effects. The Stockholm curves therefore represent the field strength at types of receiving locations which vary with distance from the transmitter, and to improve the accuracy it would be necessary to use different corrections which take these factors into account. As a result of the investigations it was considered that this procedure would be unsatisfactory. Because the terrain clearance concept seemed a more realistic approach, it was decided that a new basic propagation curve would be produced, to which appropriate terrain corrections would be applied. At the same time, in preparing the new curve, the opportunity would be taken to take account of many additional measurements (455 groups of measurements were eventually used) which had become available since the formulation of the Stockholm curves.

3.2. Description of the Field-Strength Calculation Method

The basis of the calculation method now used is the free-space (or inverse-distance) field-strength curve, to which various corrections are applied. The form of the calculation may be expressed as follows:-

$$E = F_0 + P - L_u - F_1 - F_2 + T_c \text{ dB rel. to } 1\ \mu\text{V/m} \qquad (1)$$

where E = field strength (in dB (μV/m)) of the interfering signal

F_0 = free-space field strength (in dB (μV/m)) for 1 kW e.r.p.

P = e.r.p. in dB rel. 1 kW

L_u = urban loss, taken to be a constant

F_1 = a loss proportional to the path length times a coefficient

F_2 = an additional loss introduced if the transmitter and receiver are screened from each other by the curvature of the earth; it is equal to a coefficient times the difference between the path length and the sum of the horizon distances from the terminals.

T_c = terrain correction, a gain or loss depending on the ground profile for the first 15 km from each terminal and also on the terminal aerial heights.

To derive the values for urban loss and empirical coefficients contained in F_1, F_2 and T_c the computer was used to carry out an optimization sequence in which these factors were varied until the differences between predicted and measured results were at a minimum. The values produced from this process are given in the following text.

The urban loss L_u was included because it was decided that the results should be representative of populated areas; the value produced by the computer optimization programme was 8·5 dB.

The remaining three factors, F_1, F_2 and T_c, are now described in detail, because their application in the calculation is complicated. Although they are discussed under separate headings, to some extent they are inter-dependent. The degree of this relationship is established by features unique to each propagation path.

3.2.1. The F_1 Loss

The F_1 loss is a variable which depends upon the constitution of the propagation path (land or sea), and upon the percentage time for which the field strength is required. It is equal to the distance between the transmitter and receiver (or path length) multiplied by the appropriate coefficient as follows:

1% time, land : 0·14 dB/km

10% time, land : 0·166 dB/km

1% time, sea : 0 dB/km

10% time, sea : 0·075 dB/km

3.2.2. The F_2 Loss

The F_2 loss is a variable which, like the F_1 loss, depends upon the constitution of the path and upon the percentage time. It is additional to the F_1 loss, and is only introduced if the total path length exceeds the sum of the horizon ranges of the terminal aerials. Thus, in order to determine the application of F_2 in the calculation, it is first necessary to obtain the horizon ranges.

The sum of the horizon ranges, D_H, is given by

$$D_H = C_v\,(\sqrt{h_T'} + \sqrt{h_R'}) \tag{2}$$

where h_T' and h_R' are the heights of the terminal aerials above the horizon height (defined below); if the values obtained for h_T' and h_R' turn out to be negative they are given the value 0.

It is necessary to assume a horizon height for the calculation, because information concerning the profile of the propagation path is limited to that provided for the terrain correction, i.e. 15 km from each terminal. Thus, for land paths, the intervening terrain is taken to be 120 m above sea level. For sea paths, a value of zero is used as the horizon height.

The factor C_v is a variable, which depends upon the path constitution and the percentage time. The artifice of varying the earth's effective radius is equivalent to allowing for the weather conditions, which affect the curvature of the propagation path. The factor C_v is defined by

$$C_v = \frac{\sqrt{2R}}{10^3} \tag{3}$$

where R is the effective radius of the earth in metres.

The factor C_v was included in the optimization programme, and the values obtained for the various conditions were:-

1% time, land : 3·61
10% time, land : 3·57
1% time, sea : 8·55
10% time, sea : 4·51

These values used in conjunction with the appropriate h_T' and h_R' provide the sum of the horizon ranges for each path. Values obtained from the optimization programme for the F_2 coefficient were:-

1% time, land : 0 dB/km
10% time, land : 0·0251 dB/km
1% time, sea : 0·038 dB/km
10% time, sea : 0·022 dB/km

The typical curves shown in Fig. 6 are calculated field strengths as a function of distance from the transmitting aerial. They are for an e.r.p., P, of 1 kw, and F_1, F_2 (where applicable) and urban losses are included. The terrain correction, which is described in the next section, is excluded, because its value depends upon the profile information supplied for each propagation path.

3.2.3. Terrain Correction

The final correction used in the calculation allows for the influence of terrain in the vicinity of the terminal aerials, and takes some account of the overall height of these with respect to the propagation path.

In Section 3.1 the development of the terrain clearance angle was described. While it is this angle which is manually derived and stored in the computer, the angle actually used in the calculation is redefined. The new angle which is produced is referred to as the 'terrain correction angle,' shown as α in Fig. 7. This figure shows a variety of propagation paths, and they will now be used to describe the different ways in which the terrain correction angle is applied.

It must first be emphasized that the terrain correction process is separated into two parts. The first deals with the effect of obstacles within 15 km of the terminals; the second considers the overall height of the terminal aerials with respect to the propagation path. The first process produces either zero correction or a loss; the second gives either zero correction or a gain. Both results are determined by the use of the angle α for each terminal and the extent of the correction is established by the curve shown in Fig. 8.

Returning to the first part of the terrain correction process, Fig. 7 profile (a), shows the situation for paths of less than 30 km in length; that is, paths for which $F_2 = 0$, there being no intervening path between the two 15 km terminating lengths. The terrain correction loss is derived from Fig. 8 for a single angle α which is defined by

$$\begin{array}{ll} \alpha_1 \geqslant 0,\ \alpha_2 \geqslant 0, & \alpha = 0 \\ \alpha_1 < 0,\ \alpha_2 \geqslant 0, & \alpha = \alpha_1 \\ \alpha_1 \geqslant 0,\ \alpha_2 < 0, & \alpha = \alpha_2 \\ \alpha_1 < 0,\ \alpha_2 < 0, & \alpha = \alpha_1 + \alpha_2 \end{array}$$

α_1 and α_2 are negative when the line drawn from the terminal aerial to the summit of the nearest obstacle points in an upward direction from the reference axis. When the terminal aerials are spaced by less than the sum of the distances from each to their horizon, the reference axis is a straight, unbroken line connecting the two aerials. In profile (c), the reference axis is the line drawn from the aerial to the horizon taken as 120 m for a land path and 0 m for a sea path.

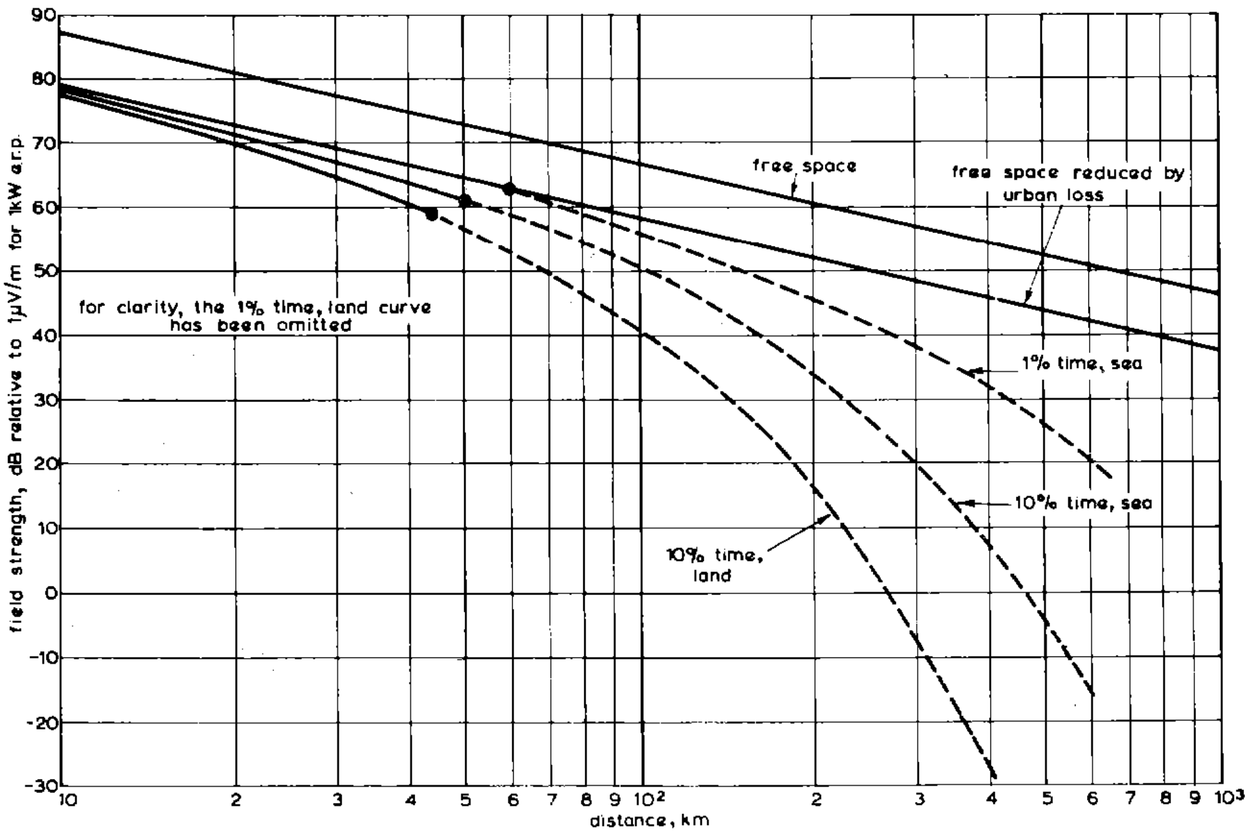

Fig. 6 - Field strength/distance curves

Representative horizon points shown thus ——●——— A solid line shows propagation within the horizon; a dashed line is used beyond this

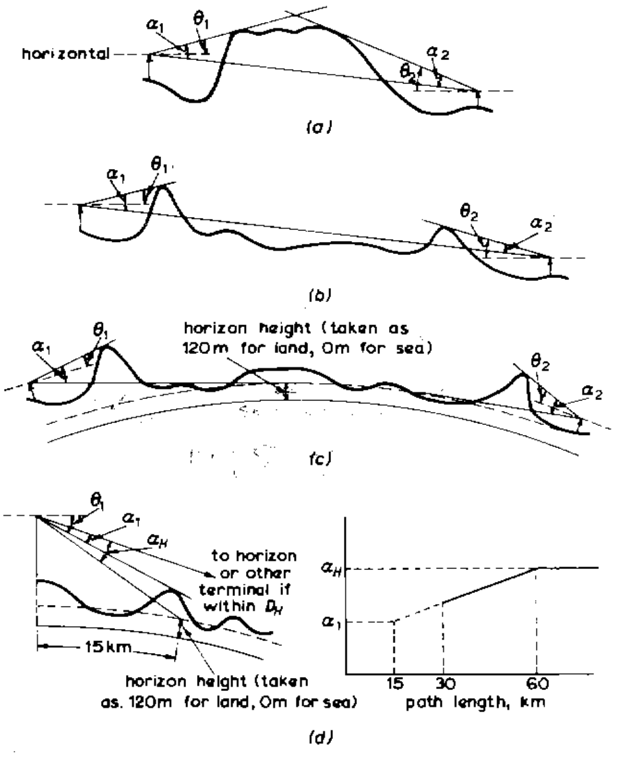

Fig. 7 - Path geometry diagrams

(*a*) Terrain correction loss; path length < 30 km (α_1, α_2 are negative in this figure)
(*b*) Terrain correction loss; path length > 30 km < D_H
(*c*) Terrain correction loss; path length > D_H
(*d*) Terrain correction gain; derivation of angles and interpolation (one terminal). (α_1, α_H are positive in this figure)

θ_1, θ_2 are terrain clearance angles
α_1, α_2 are terrain correction angles
D_H is the sum of horizon distances

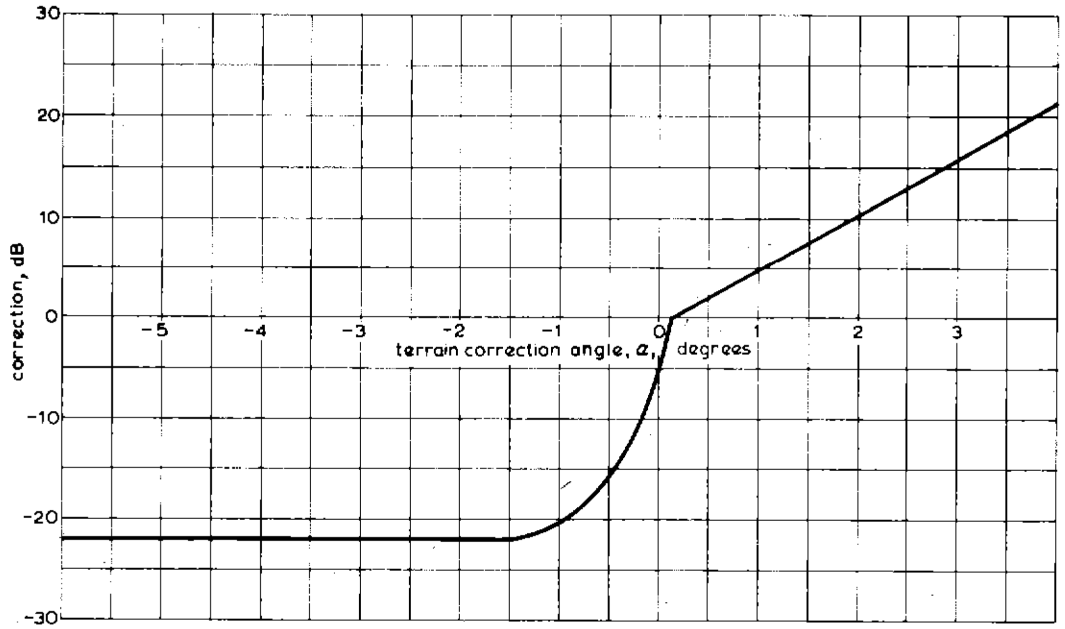

Fig. 8 - Terrain correction

From Fig. 8 it will be seen that for $\alpha = 0$ the correction is -6dB. This corresponds to the loss imposed by Fresnel theory for grazing incidence. Zero correction on the same figure is equal to a value for $\alpha = 0{\cdot}13°$, an angle which corresponds to zero loss at 600 MHz due to a knife edge at the mid-point of a 30 km path.

Profiles (*b*) and (*c*) in Fig. 7 are such that F_2 may differ from zero, because they illustrate the conditions for path lengths greater than 30 km in length. For profile (*b*), $F_2 = 0$ because the path length, although greater than 30 km, still does not exceed D_H. In this profile the datum is taken to be the line joining the terminal aerials, and α is defined with respect to this base. In profile (*c*) the path length is such that the aerials are not within the sum of the horizon ranges of each other and the base lines for α are as shown. It could well be that $F_2 \neq 0$ in this case. The corresponding losses for the profiles at each end of the paths are read off from Fig. 8 and added together because α_1 and α_2 are both negative in both examples shown.

It is now necessary to consider the second part of the terrain correction. This may be regarded as a measure of the effectiveness of a high aerial in providing a favourable path over the terrain at distances beyond 15 km from each terminal. Since precise information does not exist for this part of the path, the correction is assessed from consideration of the aerial height relative to the horizon height, as well as the terrain correction angles, α_1 and α_2.

The gain correction is applied only to path lengths in excess of 30 km in length, and is determined by the angles shown in profile (*d*) of Fig. 7. From each terminal we draw a line to the horizon if the path length equals or exceeds D_H, or to the other terminal if this is within the sum of the horizon ranges. A line is also drawn from the aerial to a point on the horizon circle, at a distance of 15 km from the terminal. The angle α_H is then defined as either the angle between these lines, or as 0·130 if a value less than this results.

For path lengths between 30 km and 60 km the angle used is a value obtained by linear interpolation as shown in Fig. 7(*d*) between the terrain correction angle α_1 (or 0·130 if α_1 is less than this value), and the angle α_H determined as described above.

The terrain correction gain is obtained from Fig. 8 for each end of the path, and the gains added. It should be noted that the slope of the curve of Fig. 8 for values of α exceeding 0·130 was derived from the optimization sequence referred to at the beginning of Section 3.2.

3.2.4. 'Mixed' Land and Sea Paths

The calculations described in the previous parts of Section 3.2 apply to all-land or all-sea paths. Various methods were tried for taking account of propagation over 'mixed' paths, i.e. combinations of land and sea, but it was eventually decided that reasonably accurate answers would be obtained if the simple 'percentage' method was used, i.e. a linear interpolation is carried out between the land and sea values (in decibels) in proportion to the length of the path over land and over sea.

3.2.5. Derivation of the Median Value and Standard Deviation of the Field Strength Distribution

For convenience in computing we require the median-time, median-location field strength of each interfering source, together with the associated standard deviations. The calculations described are based on median-location measured values, within the area for which they are applicable. The results of the calculations therefore give median-location values; the standard deviation with respect to location is 5 dB, for the reason given in Section 2.2.

As far as the distribution with respect to time is concerned, we calculate only the 1% and 10% time values for the 50% location, and then derive a median-time value and standard deviation, making the assumption that a Normal statistical distribution applies. Writing the values (expressed in decibels) for 1%-time and 10%-time, at the 50%-location, as $E_{1,50}$ and $E_{10,50}$ respectively and the median value and standard deviation as M and σ_T respectively, for a Normal distribution it can be shown that:

$$\sigma_T = 0{\cdot}956\ (E_{1,50} - E_{10,50}) \qquad (4)$$

$$M = 2{\cdot}226\ E_{10,50} - 1{\cdot}226\ E_{1,50} \qquad (5)$$

For the distant sources the median value is a fictitious one, since the distribution is not, in fact, Normal. In these cases, however, σ_T is large, so that only the field strengths for small time percentages are important, and over this part of the range the distribution approximates to a Normal one. On the other hand, for nearby sources, for which the field strength for all percentage times is important, the distribution approximates closely to a Normal one, so that the above method of calculating the median and standard deviation is adequate.

3.3. Determination of the Protected Field Strength

We have seen how to calculate the field strength of the interfering sources, and the next step is to calculate the protected field, i.e. the minimum signal strength required to provide a satisfactory service when the quality of reception is limited by co-channel interference. This problem is dealt with in Part 2$^{(1)}$ of the report, but an outline of the main considerations is given below.

For a single interfering source the protected field is given by:

Protected field = (Field strength of unwanted source)
+ (protection ratio for appropriate carrier frequency offset)
− (receiving aerial directivity allowance) (6)

In practice, the field strengths of both the wanted and unwanted sources vary from location to location and also with time, so that statistical methods must be used to define the degree of protection. The situation is complicated by the fact that a number of sources may cause interference, so that again statistical methods have to be used to assess the effect of this composite interference on the protected field.

The protection ratios to be used in Equation (6) for interference occurring for between 1% and 10%-time (i.e. protection probabilities of between 99% and 90%-time) are given in the Stockholm document. The BBC result is finally evaluated in terms of the field strength giving 95% protection probability.

To take account of the possibility of virtually continuous interference being the dominating factor, the protection ratio for each source is modified as follows. The difference between the 95%-time field and the 50%-time field is calculated; if it is say, x dB, the protection ratio is increased by (10 − x) dB. The resulting protected field will then meet the C.C.I.R. criterion for short duration interference and also the BBC criterion for virtually continuous interference (see Section 2.3.).

3.4. Discussion of New Method

The calculation method described in this report has now been in use for nearly two years, and a considerable amount of experience has been gained with it.

Three principal advantages have resulted from the adoption of the new system. Two of these are associated with the method of calculation, whilst the third has resulted from the use of a computer.

Firstly, the accuracy of the calculation is greater than that of the Stockholm document method. This is shown by the information contained in Figs. 9 to 12 inclusive, which display the comparisons between measured and predicted results at 455 receiving locations. Fig. 9 shows the comparison between measurements and predictions which have been made using the Stockholm document, whilst in Fig. 10 the measured results are compared with predictions derived by the new method. Figs. 11 and 12 are similar comparisons, but in these graphs they are shown as a function of distance from the transmitting station.

Secondly, the need for subjective correction to the results has been largely eliminated. It is necessary, of course, to select representative receiving sites for the investigation, and this still involves subjective assessment. However, this degree of selection is no greater than that which applies to most forms of field strength measurement and prediction, in which it is left to the engineer to decide the density and placing of his observations.

The use of the computer has meant that many more calculations have been carried out than would otherwise be possible. Other advantages are expected to accrue from the use of the present system. Principal amongst these must be the possibility of widespread use by other organizations of a method developed for use with a computer, which could result in a substantial reduction in the work associated with transmitting station planning. In the past, the preparation of the proposal for a new station by the broadcasting organization, the examination by the Post Office, and the subsequent investigation carried out by Continental administrations could mean that the calculations have been repeated several times. Whilst this procedure has not embarrassed the v.h.f. development, which has been gradual, some improvement is desirable for the u.h.f. service, because of the much higher planning rate. If an agreed computer method could be established between the various authorities, an application for a new station could take the form of a length of data tape, giving the operating characteristics of the proposed transmitter. Each administration could then quickly assess the effect of the new source of interference upon their own services, by using the new data in their computer programme.

There is one important disadvantage of the new method, namely, it is quite unsuited for manual use. In order to exploit to the full the advantages of large storage and speed of computation the system has been developed for computer calculation, and it is inefficient to attempt to use it manually. In one example a manual calculation took about 30 man-hours to complete. The equivalent time for the computer was rather less than one minute. The new work therefore does not improve upon any of the existing means of obtaining a rapid appraisal, unless the necessary data is already stored in the computer and on-line access or instant availability is possible.

The use of a computer for planning work has introduced other problems, although these cannot be regarded as serious disadvantages of the method. Firstly, to obtain valid answers it is essential that the data held in store should be accurate. Many changes are made every week, and considerable clerical effort is required to ensure that the computer is using current information. Secondly, the weekly output is so enormous that accurate analysis and full appreciation of the detailed results can occupy considerable engineering effort. A typical output sheet is shown in Table 2, giving the results for one receiving location; the present weekly output averages about 200 of these sheets.

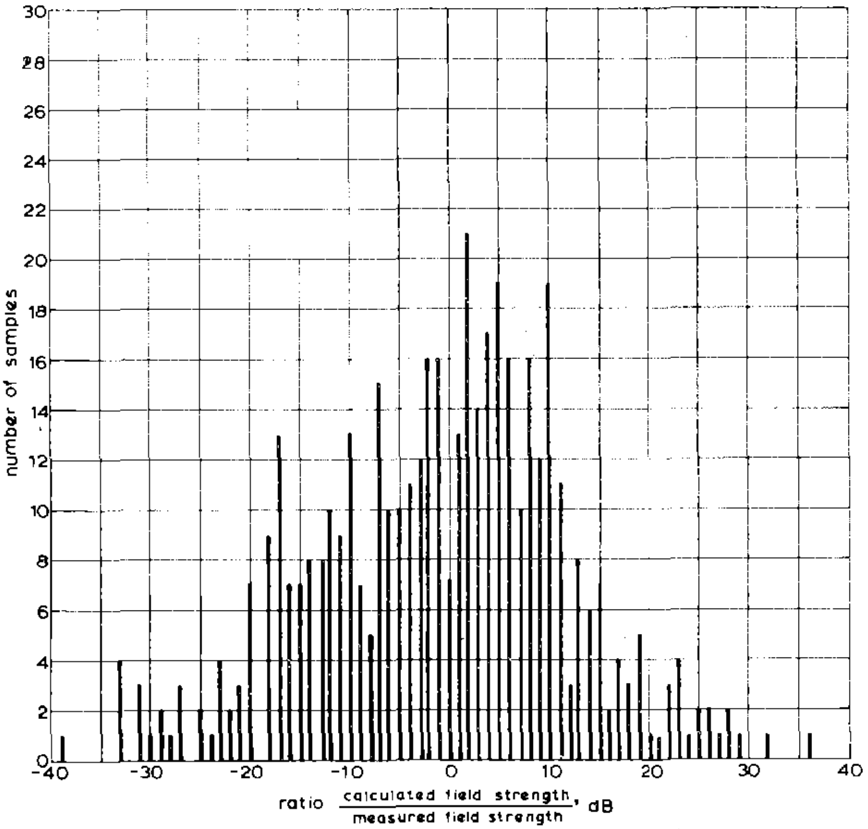

Fig. 9

Histogram of ratio of field strengths: $\dfrac{\text{Calculated by Stockholm Method}}{\text{Measured}}$

Mean = − 1·18 dB
Standard deviation = 12·6 dB

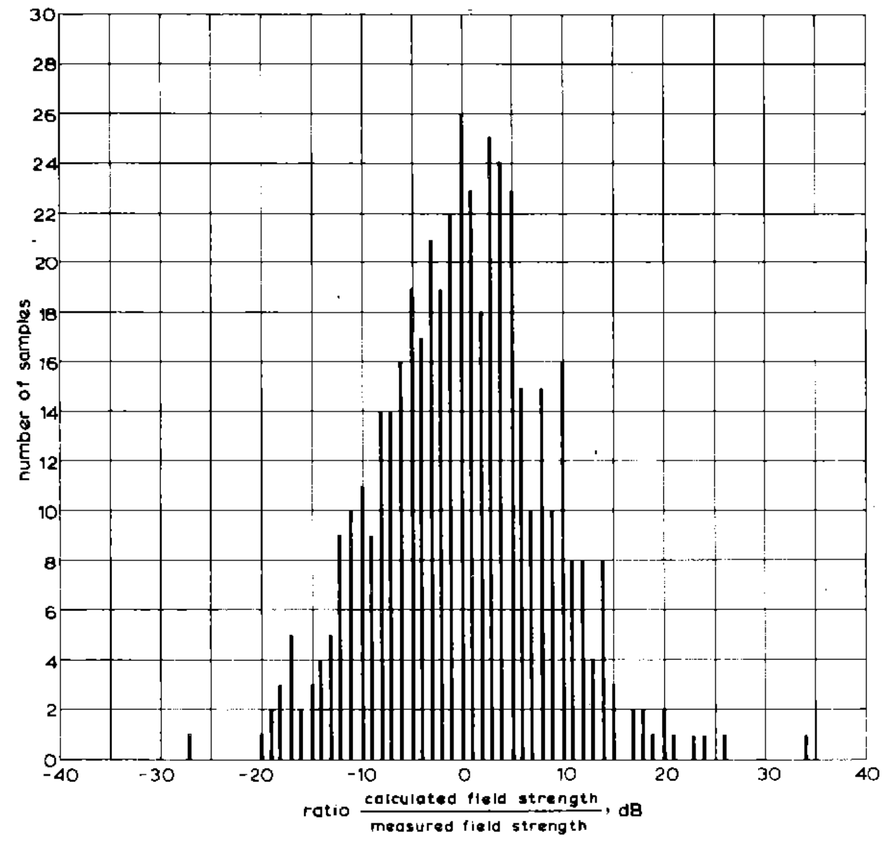

Fig. 10 - Histogram of ratio of field strengths:

Calculated by New Method

Measured

Mean = 0 dB
Standard deviation = 8·3 dB

4. FUTURE DEVELOPMENT

Current development of the c.c.i. programme is proceeding along three general lines:

(i) Improvement of the calculation method.

(ii) Improvement of the form of the computer input/output data.

(iii) Adaptation for international use.

Although there has been some improvement in the accuracy of the final result, compared with that using the Stockholm document, further improvements are being studied.

At present the results of the computer programme are used as a guide to site selection, channel choice, effective-radiated-power specification and other transmission features, as well as providing an indication of the extent of a service area. Channel selection is an important feature of the work, partly because it is this information which is used to identify stations for inclusion in the calculation, i.e. the computer programme starts by selecting from store those stations which use the channel selected for investigation. The possibility is being studied of not having to repeat the whole calculation on several channels when deciding allocations for a new station.

The main investigation into the input procedure is concerned with data checking. It is hoped that it will be possible to leave much of the effort to the computer, and means of doing this are being studied.

It was mentioned earlier that the enormous output required considerable study for full analysis. Much of this is due to the fact that all the stations stored are included in each calculation. It was considered at the start that until we had evidence of the nature of the results it would be unwise to eliminate any source. Some form of exclusion technique would be of advantage and, in a method at present under trial, calculations are first carried out for a receiving location at the wanted transmitter site, to determine which sources can subsequently be excluded on the basis that they are too weak to affect the final assessment.

The possibilities of adapting the programme for international use are being examined through Working Party K of the European Broadcasting Union; discussions are being held with representatives of various countries to study the prospects of developing an international system. At the present time it would seem that such a programme could be a simplified version of the current BBC system; simplification seems desirable because many countries have not yet proceeded far with their u.h.f. coverage plans, and are not able to supply the vast amount of data required for the full method.

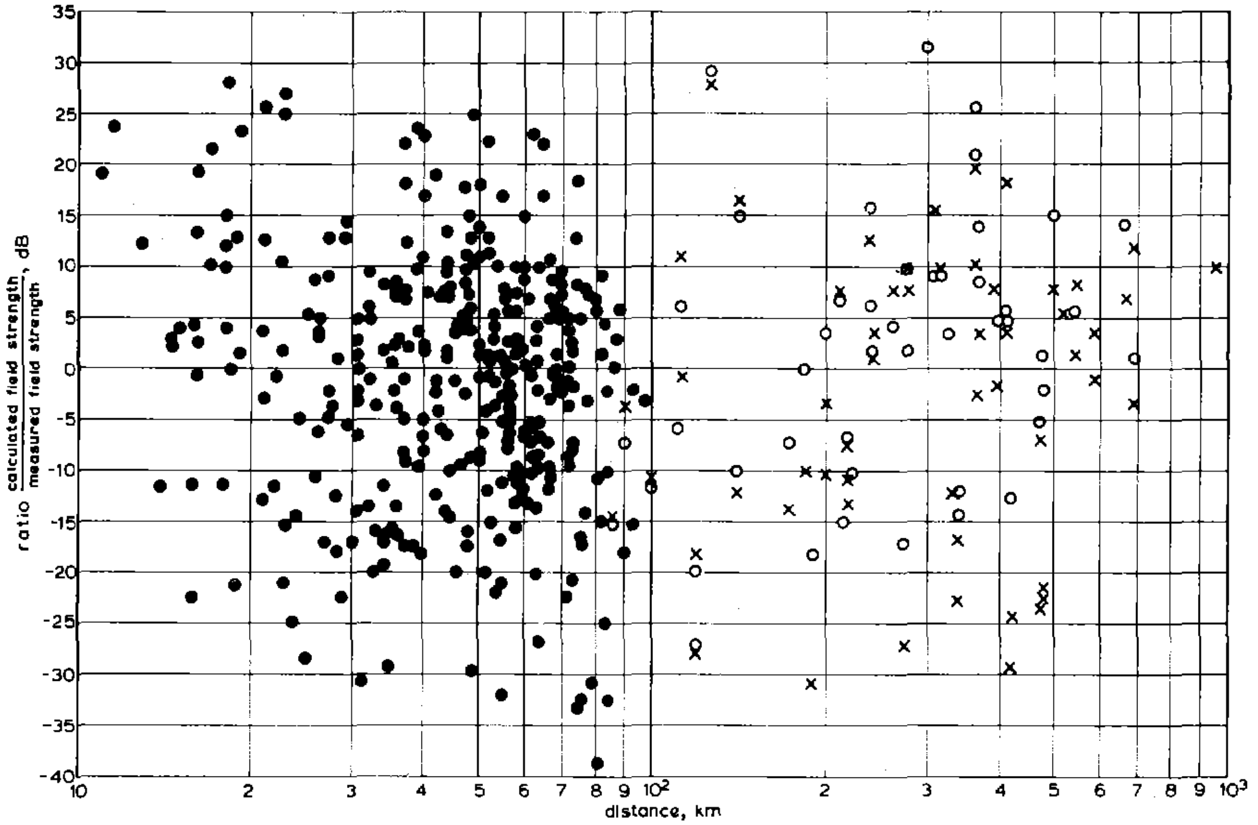

Fig. 11 - Graph of ratio of field strengths: $\frac{\textit{Calculated by Stockholm Method}}{\textit{Measured}}$ *against distance*

● 50% Time values ○ 10% Time values × 1% Time values

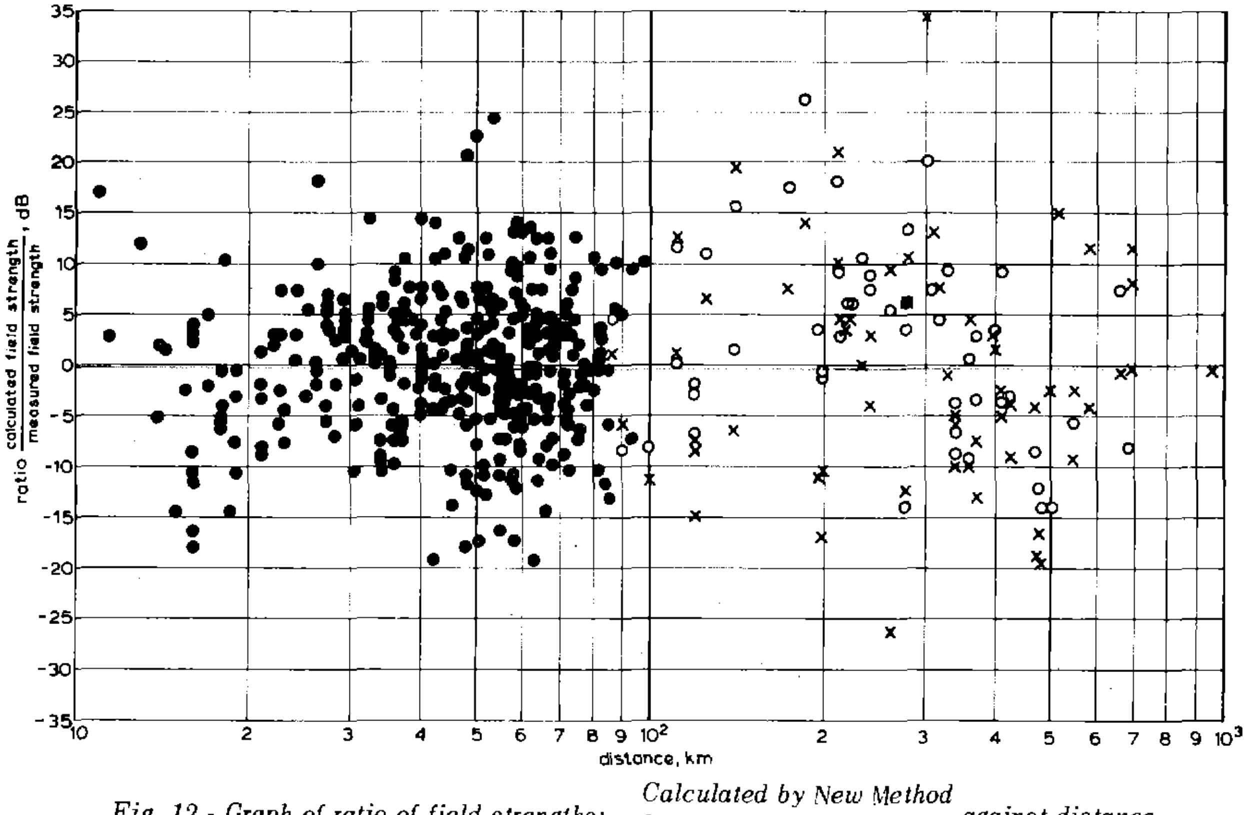

Fig. 12 - Graph of ratio of field strengths: $\frac{\textit{Calculated by New Method}}{\textit{Measured}}$ *against distance*

● 50% Time values ○ 10% Time values × 1% Time values

TABLE 2

Co-Channel Interference Calculation with Terrain Correction

Channel	Date	Service Area
26	2 / 9 / 66	C P

No.	Test Location Dist. (km) From TX	Bearing (Deg)	95% Time 50% Locn F.S. (dB) Prot.	95% Time 70% Locn F.S. (dB) Prot.	70% Locn 70 dB % Time Prot.	70% Locn 80 dB % Time Prot.
224	35·6	191·5	61·0	63·3	98·6	99·9

RELATIVE CONTRIBUTIONS

TX	50% Time 50% Locn F.S. (dB) Prot.	S.D. Time	95% Time 50% Locn F.S. (dB) Prot.	Aerial direct. (Deg)	TX Bearing (Deg)
Stratfd	14·5	6·0	24·3	303	314·6
Ramsbot	–14·5	13·9	8·3	321	332·9
Skipton	–33·2	15·4	–7·8	325	336·8
Halifax	–12·1	13·7	10·5	327	338·0
Swansea	–23·4	12·6	–2·7	271	282·6
Rhondda	–10·8	10·7	6·9	273	284·2
C Risca	21·4	8·8	35·9	273	284·8
Hexham	–55·5	20·5	–21·7	333	344·2
Cromer	13·2	10·1	29·8	13	24·2
Alburg	34·4	7·8	47·3	32	43·5
N Yorks	28·2	15·6	54·0	337	348·8
Wrekin	20·5	9·5	36·1	305	316·4
Stockld	36·7	8·0	49·9	249	260·3
Ayrshir	–60·3	26·2	–17·2	320	331·5
Banff	–91·7	36·3	–31·9	334	345·7
Lewis	–134·5	42·5	–64·6	322	333·5
Ireland					
Kippure	–12·0	25·8	30·5	288	299·5
Mulrany	–88·7	36·3	–28·9	287	298·6
S Naght	–86·9	33·9	–31·0	304	315·0
Germany					
Bonn	–61·2	25·4	–19·4	79	90·9
Fulda	–105·7	34·2	–49·4	79	90·0
Minden	–74·1	33·3	–19·3	62	73·6
Sleswig	–85·4	50·1	–2·9	44	55·2
Stutgat	–113·1	35·6	–54·5	95	106·1
France					
Besacon	–87·9	31·4	–36·2	118	129·8
Bourges	–35·0	24·3	5·1	140	151·9
Meziere	–3·3	18·9	27·7	99	110·5
Nancy	–58·6	26·2	–15·4	106	117·3
Nantes	–18·7	27·1	25·9	179	190·8
Rouen	25·4	14·3	48·9	143	154·5
Holland					
Lelstad	1·2	26·5	44·9	53	64·8
Belgium					
Molhout	–28·2	20·3	5·2	73	84·1
Norway					
Flo	–184·5	73·8	–62·9	4	15·8
Oevre	–132·0	63·8	–26·9	16	27·0

5. ACKNOWLEDGEMENTS

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APPENDIX

Terrain Clearance Protractor

The instrument is designed to obtain from contour maps a measurement of the terrain clearance angle, θ. It can also be used for other purposes such as determining the required beam tilt and confirmation that line-of-sight conditions exist between two points. The instrument, illustrated in Fig. 5 is used in conjunction with a one-inch-to-the-mile map. The mode of operation is as follows:

(i) The height of the aerial above sea level is determined.

(ii) Screw A is loosened and slider B is adjusted so that line C corresponds with the aerial height on slider D. (In the case of a 'standard receiving site,' a 30 ft. mark E is engraved on the instrument and this is aligned with the ground level figures on slider D).

(iii) The instrument is placed on the map with pin F through the location to be investigated, and with line C along the required radial. Scale G is provided to facilitate alignment with a particular bearing.

(iv) A check is made to see whether any obstruction along the radial within 15 km is higher than the aerial. If there is such an obstruction then the process is started with slider D at zero on the distance scale H. If there is no obstruction then slider D is adjusted to 15 km (approximately 10 miles) on scale H.

(v) Pointers J and K are set to maximum clockwise position.

(vi) Moving slider D along, pointer J is adjusted to correspond to map heights (as recorded at point of intersection with the scale on D).

(vii) The terrain clearance angle θ is indicated by pointer K; a subsidiary expanded scale gives values of θ between 0 and 1°.

The actual angle registered is dependent on the ratio of the vertical to horizontal scales. A scale for direct reading of the terrain clearance angle can be provided, but the prototype instrument shown in Fig. 5 was calibrated in angles from the vertical.

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